The effects of metro interventions on physical activity and walking among older adults: A natural experiment in Hong Kong

Abstract: This paper provides a causal inference on how transport intervention affects moderate-to-vigorous physical activity (MVPA) and walking among older adults using a natural experiment of a new metro line in Hong Kong. A longitudinal survey of 449 cohort participants was collected before and after the metro operation. Treatment groups live within a 400m walking buffer of the new metro stations, while control groups are located around comparable stations on existing metro lines. These metro lines were planned at the same time using similar principles, but the intervention line was built later due to different financial models. Our difference-in-difference (DID) models found that the new metro line significantly decreased older adults' weekly MVPA (-129.33 min, $p<0.05$) in treatment groups, while the effect on change in walking time did not significantly differ between the treatment and control groups. We also found heterogeneous treatment effects among gender and age subgroups. Furthermore, our time effect tests suggested that older adults' physical activity and walking levels could stabilise, based on participants living around a metro station operated four years ago with one comparable station. This practice-based evidence suggests that new metro developments might not stimulate physical activity and walking among older adults in high-density cities such as Hong Kong.

Keywords: Metro; older adults; physical activity; walking; natural experiment

1. Introduction

Physical activity is crucial for curbing chronic diseases in older people, such as type II diabetes, obesity, heart disease, and some cancers (Peterson et al., 2013). Despite these benefits, older adults seldomly achieve the weekly physical activity level (150 mins) recommended by World Health Organization (Van Cauwenberg et al., 2011). Urban rail transit could provide transformative modes for older people to achieve active living (Sun, Du, et al., 2021). However, the evidence between station proximity and physical activity is primarily based on cross-sectional research design and associational findings (Heinen et al., 2015). As a result, we still lack scientific rigour on how transport infrastructure shapes healthy behaviours to assist urban rail transit investment and modification (Hirsch et al., 2018; Jáuregui et al., 2021).

1.1 Urban rail transit, physical activity, and walking behaviours

Urban rail transit use is believed to increase physical activity and walking (Miller et al., 2015; Rissel et al., 2012), since it requires additional travel to the stations, generally by walking or cycling (Huang et al., 2017; Sun et al., 2016). Therefore, people could gain a certain amount of daily physical activity (Besser & Dannenberg, 2005; Miller et al., 2015). In addition, station catchment areas could become attractive and vibrant places for utilitarian and recreational purposes (Schoner & Cao, 2014), leading to more physical activities (Freeland et al., 2013). Several cross-sectional studies in American cities found that residents close to transit stations or public transit users had higher physical activity and walking levels than those living further away or with little transit usage (Rissel et al., 2012; Saelens et al., 2014).

Nonetheless, several confounders may distort the observed associations between urban rail transit, walking, and physical activity. For example, residential self-selection can confound the outcomes since residents with positive attitudes toward physical activity and public transit could choose to live in station catchment areas, thus having more physical activity (Lamb et al., 2020; Yang et al., 2021). Also, rail transit tends to be placed in neighbourhoods with high density and mixed land use, which may already stimulate frequent walking (Miller et al., 2015; Saelens et al., 2014). Therefore, we still need a rigorous research design for causal inference in the effects of urban rail transit on health behaviours.

1.2 Natural experiments on physical activity of urban rail transit

Recent natural experiments investigated the causal effects of different urban infrastructure interventions (e.g., greenspace and transport facilities) on individual outcomes (He et al., 2021; Stappers et al., 2022; Wali et al., 2022). For transport-related intervention, studies discovered different new transport infrastructures (walking and cycling trails, busways, and urban rail transit) to infer causal effects on health behaviours (Huang et al., 2017; Panter et al., 2016). Natural experiments assign comparable treatment and control groups to exclude the possibilities that change in an outcome in the treatment group was due to temporal trends or unmeasured confounders (He et al., 2022; Sun et al., 2022; Wing et al., 2018).

A few studies have applied longitudinal or natural experiment research design to investigate the effects of new urban rail transit on physical activity and walking (Hirsch et al., 2018). For example, Huang et al. (2017) found that people's overall walking levels decreased after the operation of light rail transit (LRT) in Seattle (US), while Miller et al.

(2016) showed that a new LRT line generated more physical activity in Salt Lake City (US). However, the two studies did not include a control group. Recent studies advanced by assigning control groups based on a certain distance threshold to the station. For example, Hong et al. (2016) suggested that the LRT's effects on active travel were significant for sedentary groups at the baseline in California (US). They considered respondents living in the station catchment as the treatment group, while those residing outside of the catchment buffers as the control group. Sun et al. (2020) found that active travel, including walking, decreased after the first metro line opened in a medium-sized Chinese city. Their treatment areas were selected from the first metro line in that city, while control groups were located around other metro lines that were planned in one package by the local government but were built later. Nevertheless, we are still short of rigorous experimental designs to study the health effects of metro interventions focusing on physical activity and walking among older adults.

In addition, different social groups may have distinctive response patterns to rail transit, and the effectiveness of the intervention depends on the needs and motivations of different groups (Wali et al., 2022). Their subsequent behavioural adaptation to the intervention may vary with different subgroups (e.g., gender, age, and socioeconomic status) (He et al., 2021). For instance, a recent study in Portland (US), showed that both positive and negative health effects might occur when there is an LRT intervention (Wali et al., 2022). However, few studies have attempted to illustrate the heterogenous treatment effects of rail transit intervention on health-related outcomes.

1.3 This study

This study investigates how a transport intervention affects older adults' physical activity and walking levels based on a natural experiment of a new metro line in Hong Kong. First, we adopted multiple treatment-control assignments in research design to estimate the average treatment effects. We set control groups near existing station areas that did not experience the new metro intervention, which was used to infer causal relationships by comparing with the treatment group. Meanwhile, we also recruited participants from another two stations to estimate the plausible time effect of metro intervention by comparing stations that started operation four years ago with another comparable one that had operated for over three decades. Second, we focused on older adults, a vulnerable group that commonly suffers from deteriorated daily mobility and health outcomes, and they may have distinctive response patterns towards metro intervention. However, how transit intervention projects affect this group is poorly understood (Hansmann et al., 2022). Our study might provide insight into whether the new metro could reshape health behaviours and exert heterogeneous effects on different subgroups. The results can assist in building ageing-friendly cities. Third, this study would supplement the evidence in high-density Asian cities. In Asian megacities, metro systems are commonly used to sustain the high-density built environment and population. It might be reasonable to assume that the specific effects in high-density cities differ from previous LRT studies in western cities.

We test the following hypotheses in this study.

- The new metro increases moderate-to-vigorous physical activity among older adults.
- The metro intervention increases walking time among older adults.
- The metro intervention has heterogeneous treatment effects among age and gender subgroups.
- Older adults' health behaviour could be stabilised at a certain time (four years in this study) after the metro intervention.

2. Method

2.1 Research design

2.1.1 Setting

Hong Kong is one of the most densely populated cities in the world. Over 7.4 million people live within 1,106 km^2, and less than 25% of the land is built-up area. Meanwhile, population in Hong Kong has experienced rapid ageing. Older adults over 65 counted for 18.9% of the population in 2018, and it is expected to reach 27.4% in 2033 (Census and Statistics Department, 2021). Mass Transit Rail (MTR) is the metro system operator in Hong Kong, and its daily ridership is about 5.5 million. The Hong Kong government has implemented a plan to expand the metro system. The lines grew from 218 km in 2012 to 266 km in 2019 and will double the length in the coming decades.

2.1.2 Data

We examine the longitudinal data from the Metro and Elderly Health in Hong Kong study. This is a natural experiment to investigate the effects of a new metro line on public transport use, physical activity, and wider health outcomes for older adults. The study protocol has been described elsewhere (Sun et al., 2021).

Our analysis for this paper is on the cohort data of the 449 older adults, with 387 participants from the treatment-control groups, while another 62 cohort data were collected for plausible time effects and robustness tests. The questionnaire-based baseline survey was conducted in 2019, before the new metro opened, with 829 participants; the follow-up survey was collected in 2021, after the new metro had been in operation for half a year, with 449 returns for the study. Specifically, we recruited participants from 14 Neighbourhood Elderly Centres for the baseline survey, including participants from treatment areas (e.g., around the new metro stations) and control areas (e.g., similar neighbourhood environments without new metro). The government-funded neighbourhood elderly centre in Hong Kong provides community support services for older people (e.g., health education, social and recreational activities). Quota sampling was used to recruit participants from the centres' members, considering age distribution, gender balance, and home locations (Du et al., 2022). Participants were aged 65 or above, living within eight metro station areas in Hong Kong, and could walk unassisted for at least 15 minutes. Trained interviewers conducted a face-to-face interview with each participant using questionnaires.

Ethical approval for the study was obtained from the Human Research Ethics Committee of The University of Hong Kong (reference number: EA1710040), and written informed consent was provided by each participant.

2.1.3 Intervention, treatment, and control groups

Fig. 1 shows the multiple treatment–control group assignment. Three treatment groups were located around the new metro line (Fig. 1), and participants were older adults living in 400m buffered areas of the new stations. Metro lines have extended to major residential areas due to the lineage built up areas between mountains and sea. Specifically, over half of residents in Hong Kong live within 500 meters of MTR stations. The 400 m distance to the station generally needs 10 minutes for older adults on average, which is the average travel time for people choosing transit service. Three control groups consisted of participants residing in station catchments that were comparable in neighbourhood types, regional accessibility, socioeconomic status and demographics, but the control stations were in operation for over 15 years (Sun, Du, et al., 2021). We tested the effects on physical activity and walking behaviour by comparing the treatment group with the control group during the pre- and post-metro intervention periods.

Local metro planning knowledge justified the rationales of this treatment-control group comparison (Sun et al., 2022). We aim to estimate what changes would have occurred in the absence of the interventions. Previous studies have suggested: (a) using nearby 'matched' control sites, interventions that had been proposed but which were not later selected for the final programme of investment; and (b) the intervention would be completed at a later date, which could then serve as a 'lagged' or 'waiting list' control

(Ogilvie et al., 2012). We used similar principles in this study. Working with local transport planners, we verified the general rationale for MTR to construct new metro lines, including being financially viable through land value capture that relies on the "Rail+Property" model to recover the new metro investment (Cervero & Murakami, 2009). In a high-density city like Hong Kong, almost all neighbourhoods meet the population density required to support passengers to a metro line (Aveline-Dubach and Blandeau, 2019). The treatment and control groups lie in metro lines planned in one package a few decades ago, but the control metro lines were built earlier, while the treatment line was built later due to a lack of a financial model to fund the metro line (Loo et al., 2018). It was until 2007 that the government applied a concession model whereby this new metro line became possible. In addition, older people's travel needs and health implications from the metro infrastructure were never at the centre of planning considerations for MTR. When recruiting participants, we also required length of residence (living at least three years in the neighbourhoods) to exclude self-selection confounding (Heinen et al., 2018). All these ensured the group comparability from the treatment-control assignment.

In addition to the above treatment-control group setting, we estimate the plausible time effect of metro intervention by recruiting participants from another two stations. After discussing with local transport planners, two comparable stations on the Island Line were selected. Specifically, Sai Ying Pun station went into service in 2015, and North Point station was in operation for over three decades. We aimed to compare the longitudinal data from Sai Ying Pun station participants with those in North Point station in 2019 and 2021 to investigate the difference in physical activity and walking behaviours. If there is no difference in the health outcomes after four years by comparing the two stations, it might suggest the treatment effects of metro interventions were stabilised. This process may provide clues for the plausible time effects of the metro intervention.

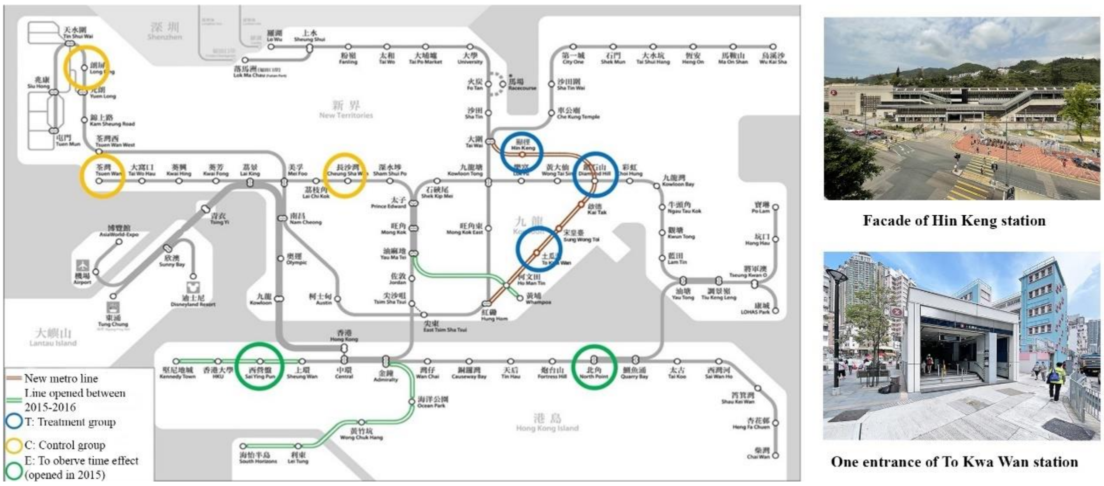

Fig. 1 Treatment and control groups in this study

2.2 Measures

2.2.1 Physical activity

The Chinese version of the short-form International Physical Activity Questionnaire (IPAQ) for the elderly was used in surveys, which has high validity in assessing different aspects of physical activity in Chinese older adults and the local context (Barnett et al., 2016). Moderate physical activity was assessed by asking questions: “During the last seven days, how many days did you do moderate physical activities at least 10 minutes at a time?” and “How much time in total did you spend on one of those days doing moderate physical activities?”. Similarly, vigorous physical activity was also reported based on two questions. Total moderate-to-vigorous physical activity (MVPA) duration in minutes per week was calculated from the baseline and follow-up surveys.

2.2.2 Walking behaviours

The self-reported walking behaviours were also retrieved from IPAQ: (1) “How many days did you travel on foot for work, recreation, or exercise purposes for at least 10 min in the past seven days?” and (2) “How long did you spend on walking per day on average, in the past seven days?”. The total walking time (in minutes) in the last seven days was calculated from the baseline and follow-up surveys.

2.2.3 Neighbourhood built environment attributes

The neighbourhood environment was defined as 400m walking distance from an individual’s home. A 400m pedestrian network buffer is a used criterion to determine the neighbourhood environment in Hong Kong due to high-density and mixed land use patterns. We geocoded respondents' residential addresses and manipulated street network analysis in a Geographic Information System (ArcGIS Pro 2.0, Esri).

Built environment attributes were calculated based on the “5D” framework, including measures of density, diversity, design, destination accessibility, and distance to transit (Sun et al., 2018). For density, a population density was extracted from population census data in 2016. In Hong Kong, the block census tract unit was demarcated by streets, and population census data contained the number of household members. Therefore, we calculated the population number of each buffer based on covered blocks of the network. Regarding the design, the 3D pedestrian network in Hong Kong provides fine-scale information about pedestrians (Sun et al., 2021), and we calculated the density of pedestrian network intersections. For diversity, we used destination diversity to depict land use patterns based on fourteen types of POI categories (e.g., commercial, retail, and education) (Sun et al., 2018). Regarding destination accessibility, we incorporated the density of parks, and restaurants within each buffer, based on POIs data. For distance to transit, we calculated the walking distance from respondent’s home to the nearest metro station entrance after the new metro line, based on the pedestrian network. In addition, we also calculated the density of bus stations.

2.2.4 Covariates

Our covariates included age (65-79, and 80 and above), gender, marital status (married vs others), education level (secondary school or below vs post-secondary), employment status (employed vs others), and housing type (public housing vs others). Self-reported overall health (ranging from 1 to 5) and monthly income were continuous variables. The year of residency (longer than 3 years) controls for the residential self-selection issues.

2.3 Statistical analysis

2.3.1 Treatment effect analysis

To assess the treatment effects of metro intervention, we applied difference-in-difference (DID) regression models to the panel data. Our DID model assumed that the new metro line induced the increased physical activity and walking difference in physical activity and walking behaviours between the two groups. We first only included intervention-related variables for the physical activity in Model 1, and we then added individual and built environment covariates in Model 2 to reduce the error variance. Similarly, walking behaviours were analysed in Models 3 and 4. The estimates held if the interaction term (e.g., treatment × time) remained statistically significant after adding covariates. The model specification is as follows:

$$Outcome_{it} = \beta_0 + \beta_1\, Treatment_i + \beta_2\, Time_t + \beta_3\, Treatment_i \times Time_t + \beta_4\, Covariates_i + \varepsilon_i$$

$Outcome_i$ is the weekly physical activity or walking time of respondent i, β_1 captures the net difference between participants in treatment and control groups, β_2 captures the change in outcomes between the participants in the baseline and the follow-up stages, and β_3 is the net difference between baseline and follow-up survey, and $Treatment_i \times Time_i$ is an interaction term indicating the treatment effects of metro intervention. $Covariates_i$ are vectors of individual and environment covariates, while ε_{ij} is the error term. In addition, based on the before and after data, standard errors are clustered at the individual level.

We conducted several stratifications to test the heterogeneous metro intervention responses across socio-demographic strata. Separated DID models were fitted for gender (male vs. female) (Models 5 and 7) and age (65-79 years vs. above 80) (Models 6 and 8). If the significant level of the interaction item is different across different groups, it means that the effects of the metro intervention vary among groups.

2.3.2 Time effect and Robustness tests

We assessed whether the changes in older adults' health behaviour would be stabilised after the intervention by comparing participants from Sai Ying Pun station with North Point station (Fig. 1) to investigate the plausible time effects of the intervention (Models 9 and 10). In addition, we added the participants (N=62) living around two stations on Hong Kong Island (green buffers in Fig. 1) to the samples in the main analysis for other robustness tests (Models 11 and 12).

3. Results

3.1 Descriptive results

Table 1 shows the descriptive results. We found no significant differences in treatment and control group for individual characteristics, except for living in public housing. For the groups to observe time effects, they were more likely to be married and had a lower rate of residing in public housing. For the built environment characteristics, the treatment and control groups were largely similar in terms of street intersections, destination accessibility, and the density of restaurants. However, population density, walking distance to the nearest metro station, and density of bus stops had disparities between the two groups.

Regarding the MVPA, both groups had declined patterns after the intervention. Paired t-tests suggest significant differences between the treatment group and control group in the MVPA changes ($p < 0.01$), with treatment groups declining in a larger amount (-132 mins vs -48 mins). Treatment groups increased walking while the control groups decreased, and the changes in walking time were significantly different in the t-test ($p < 0.01$). The average length of residency in treatment groups was 26 years, enabling this study to exclude self-selection confounding.

Table 1. Descriptive statistic results (N=449)

	Treatment group (Blue in Fig. 1)	Control group (Yellow in Fig. 1)	Two stations for time effects (Green in Fig. 1)	Overall group
	Mean (SD)/%	Mean (SD)/%	Mean (SD)/%	Mean (SD)/%
Weekly walking time at baseline (min)	781.6 (443.0)	752.1 (397.7)	706.2 (407.4)	758.0 (418.2)
Weekly walking time at follow-up (min)	841.4 (482.2)	763.0 (484.8)	726.6 (478.3)	790.5 (483.8)
Changes in weekly walking time (min)	59.8 (545.1) ***	10.9 (558.5)	20.4 (489.5)	32.5 (543.2)
Weekly MVPA time at baseline (min)	658.1 (544.0)	481.8 (496.8)	519.8 (442.2)	561.0 (518.2)
Weekly MVPA time at follow-up (min)	526.4 (485.5)	471.8 (442.3)	451.5 (423.8)	495.7 (467.7)
Changes in weekly MVPA time (min)	-131.7 (524.9) ***	-10.0 (568.3)	-68.4 (577.4)	-68.5 (553.7)
Age (65-79 years old=1)	68.8	68.7	79.0	69.7
Female (Yes=1)	60.2	69.2	61.3	64.4
Post-secondary school (Yes=1)	5.3	4.7	1.5	5.0
Employed (Yes=1)	4.6	1.2	5.6	1.8
Married (Yes=1)	59.7	41.8	75.8	57.5
Public housing (Yes=1)	30.1	68.1	5.6	44.9
Years of residency	26.3 (12.4)	19.8 (12.4)	23.9 (12.2)	24.2 (13.5)

Self-report health (1-5)	3.4 (0.9)	3.5 (0.8)	3.5 (0.9)	3.5 (0.9)
Monthly income (in 1,000 HKD)	4.4 (3.4)	4.1 (2.2)	5.8 (6.0)	4.6 (3.9)
Population density (in 1,000 per km^2)	140.8 (77.1)	111.9 (67.8)	180.3 (75.5)	121.0 (77.1)
Density of street intersections (per km^2)	1109.7 (484.6)	1171.3 (287.5)	1055.6 (504.7)	1214.6 (458.9)
Density of parks (per km^2)	3.2 (7.0)	3.5 (7.8)	1.6 (3.0)	2.0 (4.9)
Walking distance to nearest metro station (m)	569.4 (300.3)	694.8 (696.1)	344.0 (174.3)	658.1 (510.4)
Density of bus stops (per km^2)	36.1 (22.0)	58.0 (30.6)	57.1 (22.6)	57.3 (32.7)
Density of restaurant (per km^2)	490.6 (525.0)	281.7 (203.9)	242.7 (154.1)	441.3 (390.2)
Destination accessibility (0-1)	0.6 (0.1)	0.7 (0.1)	0.6 (0.2)	0.6 (0.1)
N (respondents)	186	201	62	449

Note: p-values were based on pairwise t-tests, *p < 0.10, **p < 0.05, ***p < 0.01.

3.2 Treatment effect analysis

3.2.1 New metro on physical activity

Table 2 summarises the DID results for MVPA. The coefficient of the interaction term in Model 1 was negative and significant (p<0.01). The treatment effect size and direction of interaction terms persisted after adjusting for covariates (Model 2), indicating that the treatment effect was a decrease of 129.33 mins weekly MVPA after the metro intervention.

In terms of covariates, the younger (less than 80 years old) groups were more likely to have higher MVPA levels. Being employed and having a longer year of residency was associated with less MVPA than their reference categories. In addition, destination accessibility and density of parks were associated with more MVPA.

Table 2. DID models of the metro intervention and changes in weekly MVPA (N=387)

	DV: MVPA	
	Model 1	Model 2
	Coefficient (standard error)	Coefficient (standard error)
Intervention		
Treatment (treatment vs. control)	176.33 (53.13) ***	184.30 (61.04) ***
Time (post- vs. pre-intervention)	-10.00 (40.12)	0.27 (41.33)
Treatment × time	-121.72 (55.61) **	-129.33 (56.31) **
Individual covariates		
Age (ref.= 80 and above)		133.81 (43.26) ***
Education (ref.= secondary school or below)		-110.76 (86.11)
Female		76.43 (43.08)
Employed		-40.05 (23.43) **
Married		-11.30 (41.38)
Public housing		72.26 (42.30)
Year of residence		-3.75 (1.34) ***
Self-reported health		19.35 (18.81)
Individual monthly income		-0.01 (0.01)
Built environment characteristics		
Population density		-0.43 (0.28)
Destination accessibility		264.12 (153.08) ***
Density of street intersection		0.02 (0.05)
Density of parks		12.06 (5.58) **
Density of bus stops		1.16 (0.72)
Walking distance to the nearest metro station		-0.05 (0.03)
Constant	481.77 (35.07) ***	410.90 (161.01) **
R-square	0.02	0.10
N (participants)	387	387

Note: *p < 0.10, **p < 0.05, ***p < 0.01.

3.2.2 New metro on walking time

Table 3 shows the effects of the metro intervention on weekly walking time among older adults. The coefficient of the interaction term in Model 3 was insignificant, indicating that the treatment effects on weekly walking time were insignificant compared with control groups (Model 3). Furthermore, the insignificance remained after adjusting covariates (Model 4).

For covariates in Model 4, only two variables are significant: women tended to have more weekly walking time, and the density of parks was negatively associated with walking time.

Table 3. DID models of metro intervention and changes in weekly walking time (N=387)

	DV: Walking	
	Model 3	Model 4
	Coefficient (standard error)	Coefficient (standard error)
Intervention		
Treatment (treatment vs. control)	29.53 (42.95)	108.63 (58.10) **
Time (post- vs. pre-intervention)	10.92 (39.42)	16.24 (39.85)
Treatment × time	48.84 (56.16)	46.88 (56.75)
Individual covariates		
Age (ref.= 80 and above)		-41.24 (42.81)
Education (ref.= secondary school or below)		-98.87 (87.42)
Female		83.04 (37.15) **
Employed		-5.16 (16.01)
Married		20.45 (38.79)
Public housing		31.56 (43.28)
Year of residence		-1.89 (1.39)
Self-reported health		2.67 (17.29)
Individual monthly income		-1.89 (1.39)
Neighbourhood covariates		
Population density		-0.11 (0.29)
Destination accessibility		-107.16 (167.49)
Density of street intersection		0.01 (0.06)
Density of parks		-11.72 (3.44) ***
Density of bus stops		0.44 (0.76)
Walking distance to the nearest metro station		0.02 (0.05)
Constant	752.11 (28.08) ***	749.57 (160.21)
R-square	0.01	0.04
N (participants)	387	387

Note: *p < 0.10, **p < 0.05, ***p < 0.01.

3.3 Subgroup difference

Stratified models examined whether the treatment effects of the metro intervention are distinctive for subgroups. Regarding the MVPA (Table 4), gender-stratified models showed that the intervention had more profound effects for the female group, while the effect on male participants was insignificant. We also observed disparities among age-stratified groups, and older group's (80 years old and above) MVPA was more sensitive to the metro intervention.

In terms of the walking time (Table 5), heterogenous treatment effects were not observed for gender subgroups. Meanwhile, age-stratified models also showed no different effects across the two age groups.

Table 4. DID models of the change in MVPA for socio-demographic subgroups

	DV: MVPA			
	Model 5a (male)	Model 5b (female)	Model 6a (65-79 years old)	Model 6b (80 and above)
	Coefficient (standard error)	Coefficient (standard error)	Coefficient (standard error)	Coefficient (standard error)
Treatment (treatment vs. control)	184.04 (101.36) *	165.31 (75.97) *	164.20 (75.271) **	208.29 (96.46) **
Time (post- vs. pre-intervention)	14.97 (58.34)	-7.51 (54.00)	-39.87 (53.31)	81.22 (62.94)
Treatment × time	-99.54 (84.84)	-146.82 (74.04) **	-108.39 (71.80)	-181.14 (89.06) **
Covariates	Yes	Yes	Yes	Yes
Constant	-113.49 (241.70)	801.48 (206.09) ***	525.26 (200.78) **	127.52 (279.52)
R-square	0.23	0.08	0.08	0.20
N (participants)	136	251	264	123

Note: (1) *p < 0.10, **p < 0.05, ***p < 0.01.

Table 5. DID models of the change in walking time for socio-demographic subgroups

	DV: Walking			
	Model 7a (male)	Model 7b (female)	Model 8a (65-79 years old)	Model 8b (80 and above)
	Coefficient (standard error)	Coefficient (standard error)	Coefficient (standard error)	Coefficient (standard error)
Treatment (treatment vs control)	63.64 (84.06)	126.41 (75.95)	66.72 (66.00)	202.98 (110.71)
Time (post- vs. pre-intervention)	16.63 (57.63)	11.70 (51.96)	-20.69 (49.32)	-96.87 (68.98)
Treatment × time	19.43 (88.18)	71.05 (73.39)	86.14 (69.87)	-38.32 (100.18)
Covariates	Yes	Yes	Yes	Yes
Constant	622.43 (206.60) ***	971.03 (211.32) ***	933.85 (182.81) ***	316.30 (305.97)
R-square	0.06	0.07	0.07	0.11
N (participants)	136	251	264	123

Note: (1) *p < 0.10, **p < 0.05, ***p < 0.01.

3.4 Time effect and robustness tests

The results of time effect tests revealed no difference in the health behaviours among older people living around Sai Ying Pun station from those around North Point station (Model 9 and 10). This might imply that older people's MVPA and walking time stabilised within four years after the metro intervention.

Regarding the robustness tests shown in Table 7, the significance and coefficient of interaction items remained stable after incorporating the participants around the two stations on Hong Kong Island (Model 11 and Model 12), compared with results in Table 2 and Table 3.

Table 6. Time effect tests: DID models comparing Sai Ying Pun with North Point groups

	DV: MVPA	DV: Walking
	Model 9	Model 10
	Coefficient (standard error)	Coefficient (standard error)
Treatment (Sai Yin Pun vs. North Point)	-105.81 (170.74)	-75.72 (154.48)
Time (post- vs. pre-intervention)	-45.02 (120.60)	-35.45 (126.72)
Treatment × time	32.55 (161.99)	84.47 (147.86)
Covariates	Yes	Yes
Constant	162.59 (382.78)	639.73 (344.65) *
R-square	0.13	0.26
N (participants)	62	62

Note: *p < 0.10, **p < 0.05, ***p < 0.01.

Table 7. Robustness tests: DID models incorporating all the sited stations

	DV: MVPA	DV: Walking
	Model 11	Model 12
	Coefficient (standard error)	Coefficient (standard error)
Treatment (treatment vs. control)	155.58 (53.83) ***	86.17 (48.34) *
Time (post- vs. pre-intervention)	-16.36 (36.04)	14.39 (33.81)
Treatment × time	-110.53 (52.82) **	48.04 (52.73)
Covariates	Yes	Yes
Constant	304.98 (140.06)	708.25 (140.87)
R-square	0.10	0.05
N (participants)	449	449

Note: *p < 0.10, **p < 0.05, ***p < 0.01.

4. Discussion

Asian high-density cities have invested massively in metro infrastructure and used them as the backbone of public transport systems. However, few studies leveraged those metro interventions to provide scientific evidence on how these new transport infrastructures affect physical activity and walking levels among older adults. Using a natural experiment approach, this paper reported causal relationships between the new metro line and health behaviours among older adults in Hong Kong. Our DID models showed that the new metro significantly decreased older adults' weekly MVPA but did not affect weekly walking time. We also found that the female and older (above 80 years old) groups are more affected by the intervention. Furthermore, these treatment effects on the changes in health behaviours could be stabilised within four years, as implied in our time effect tests.

4.1 Natural experiment research design

We advanced the natural experiment research design in treatment-control group assignment leveraging urban planning knowledge. In the ultra-high-density city of Hong Kong, built-up areas require metro service, and almost all the metro lines in this study were conceptualised in one package a few decades ago. However, due to the land (re-) development potential of the business model of the metro company, certain areas lagged in metro provision. We used the groups around stations built earlier as the control group because of the above planning context. In such settings, the consideration to have (or not) a metro station was neither because of the built environment features nor the older adults' health impacts. Meanwhile, defining a clear cut-off point is always challenging, and residents in the control groups may also use the new transit service (Humphreys et al., 2016). Using the 'lagged' or 'waiting list' control group, we ensured that control groups were comparable with the treatment groups and would not be affected by the new stations (McCormack et al., 20212012).

Furthermore, we created multiple treatment-control groups based on the opening time of metro stations. Our results revealed both the short-term treatment effect and insights into the plausible time effect, which supported a stronger inference of the behavioural changes. In summary, our research design would have improved internal validity, including comparable treatment-control groups, balanced baseline characteristics, and covariates adjustment (McCormack et al., 2021).

4.2 Causal effects of metro intervention

This study has four main findings. First, the results showed that the new metro significantly decreased older adults' weekly MVPA. This result rejected our first hypothesis. It seems reasonable to assume public transit use would lead to more physical activities, and previous cross-sectional studies also indicated higher physical activity among transit users than non-users (Knell et al., 2018). However, recent natural experiments in both American and Asian contexts suggested that transit interventions could reduce overall physical activity for the general population (Hirsch et al., 2018; Sun et al., 2020). Our study provided further evidence that metro intervention reduces the MVPA of older adults in a high-density city. A possible explanation is that the intervention changes older adults' daily mobility patterns, and some of their trips previously by active travel and bus were replaced by metro trips. As a result, the former have more physical activities involved than the latter. It is also possible that more public transport use (including the metro) may substitute the time for recreational physical activity (Lachapelle et al., 2016). Moreover, we observed a much higher reduction than in previous studies (weekly 80.4 mins decrease on average for the general population using meta-analysis) (Hirsch et al., 2018).

Second, we did not observe significant effects of the metro intervention on walking time for the overall group. The results rejected our second hypothesis. Our findings differed from recent studies highlighting a decreased overall walking time (McCormack et al., 2021; Sun et al., 2020). This is possibly due to the local characteristics of older adults in Hong Kong (Cerin et al., 2014), who maintain a high walking level (weekly 766.4 mins on average at baseline and remained relatively stable in the follow-up survey). Walking habits could interact with the metro intervention's effects on behaviour change. Previous studies suggested that health behaviours of past active groups might not be sensitive to a new transit intervention (Hong et al., 2016). Another possible explanation is that the provision of metro stations would not significantly change the overall distance to public transport (McCormack et al., 2021), thus unlikely to affect overall walking.

Third, we found heterogeneous treatment effects on MVPA among gender and age subgroups. Based on cross-sectional observations, previous studies suggested that specific groups may rely more on public transit than others (Hsu et al., 2019), and distinctive treatment effects of new LRT on health outcomes among different population groups may occur (Wali et al., 2022). Our study further confirmed distinctive behavioural response patterns to the new metro service. Specifically, the intervention on change in MVPA was more profound in females and older groups (aged 80 or above). However, we did not observe any disparity in different subgroups regarding metro intervention on walking time change.

In addition, we provided a modest investigation of the time effects of the metro intervention on health behaviour changes. It was unclear whether individuals took a long time to stabilise their behaviours after rail transit intervention. It is possible that individual's physical activity level changed immediately after the provision of the new metro service, due to the heavy reliance on metro system. It was also possible that continuous change may occur, due to the potential effects of the "novelty factor" on long-term change or lagged effect of built environment intervention on daily activity (Hunter et al., 2015). Therefore, the varying treatment effects over time urged the need to use different assessments to investigate time effects. In the main analysis, we found that metro intervention on the change in health behaviours did not take long to exert treatment effect (e.g., half a year). In our time effect tests of the two stations, we found these health behaviours might be stabilised four years after the operation. Previous investigations in western settings found transportation behaviour has not been stabilised between two and four years after transit intervention (Heinen et al., 2017). Our findings might provide new insights into the time effects of transport infrastructure intervention.

4.3 Policy implications

The findings have several policy implications for Hong Kong, which may also be valuable for other cities with similar contexts (e.g., Singapore and Tokyo). First, the presumed health benefits of the metro on older adults in high-density cities need to be re-evaluated since we did not observe positive effects on total physical activity and walking. Although the metro may facilitate daily convenience, policymakers and transport planners should be cautious about its impact on creating a more active lifestyle. Second, metro intervention is complex, and policymakers should pay more attention to synergetic effect of metro access and facilities improvement to maintain physical activity. For instance, more high-quality pedestrian infrastructures (e.g., elevators and escalators) could be provided in station catchment areas. Apart from physical environment modifications, several programmes are needed to assist different groups of older people in creating an age-friendly mobility environment. For instance, targeted policies (e.g., support from staff and specific turnstiles in the station) could be provided to facilitate their travel experience.

4.4 Strengths and limitations

Our study has a few limitations. First, we used self-reported physical activity and walking data, thus prone to recall or social desirability bias (Adams et al., 2009). Nonetheless, self-reported data ensured larger sample sizes and distinguished domain-specific behaviours (e.g., metabolic levels). Second, a more sophisticated approach (e.g., simulation-assisted heterogeneous behavioural models) could be used in future studies, providing richer inferential insights into heterogeneity contours (Wali & Frank, 2021; Wali et al., 2022). Third, the outbreak of the fifth wave of COVID-19 in Hong Kong decreased the retention rate and sample size in the follow-up survey. However, when we conducted the follow-up and after the metro went into operation for seven months, there were zero local covid cases in the city due to a stringent 14-day hotel quarantine policy for outsiders. Last, we did not incorporate attitudinal attributes of older adults towards metro use due to the constraints of the dataset, and future studies could incorporate it in the analysis (De Vos et al., 2022).

The study also has notable strengths. First, we advanced the research design with multiple treatment-control assignments, which helped us to reach stronger causal estimates (average treatment effects and plausible time effects) of metro intervention on physical activities and walking. Second, this is the first study targeting metro intervention on health behaviour changes among older adults, which provided explicit evidence on this vulnerable group. Third, we advanced the understanding of metro intervention on the changes in physical activity and walking levels in high-density cities, which has planning and policy implications for the synergies between public transport and healthy ageing cities.

5. Conclusion

Natural experiments provide causal evidence to evaluate the impact of the new metro line on health-related outcomes. Our study indicates how a new metro line in Hong Kong changes MVPA and walking among older adults. Results show that the new metro decreased weekly physical activity, while no significant effects on walking time changes between the treatment and control groups were found. Furthermore, robustness tests show that older adults' health behaviour could already be stabilised four years after intervention. The results call for caution in assuming that metro investments would inevitably promote healthy behaviours among older people. Hence, policymakers need to develop synergetic approaches to sustain active travel and physical activity levels of older adults.

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